Integrated Inspection for Precision Part Production

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Motivation

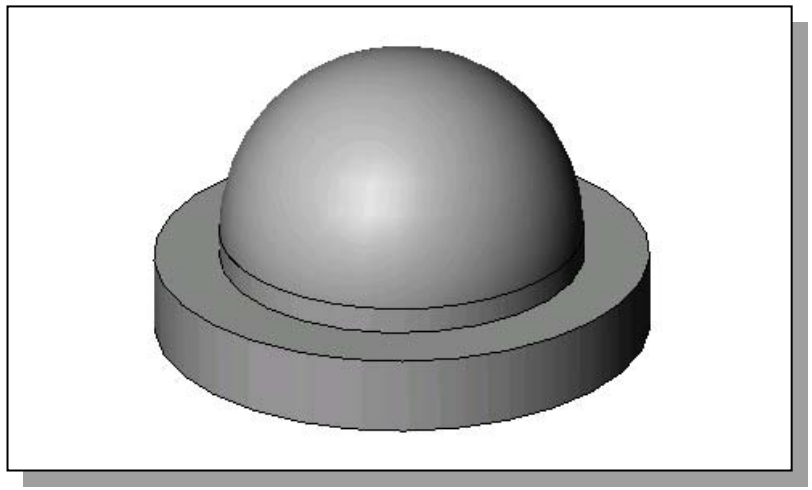
- Precision machining
  - Smaller custom jobs
  - Tight tolerance
  - Procedure
    - Cut part, remove part, then inspect
    - Scrap or setup workpiece again
  - **Correct before removal**

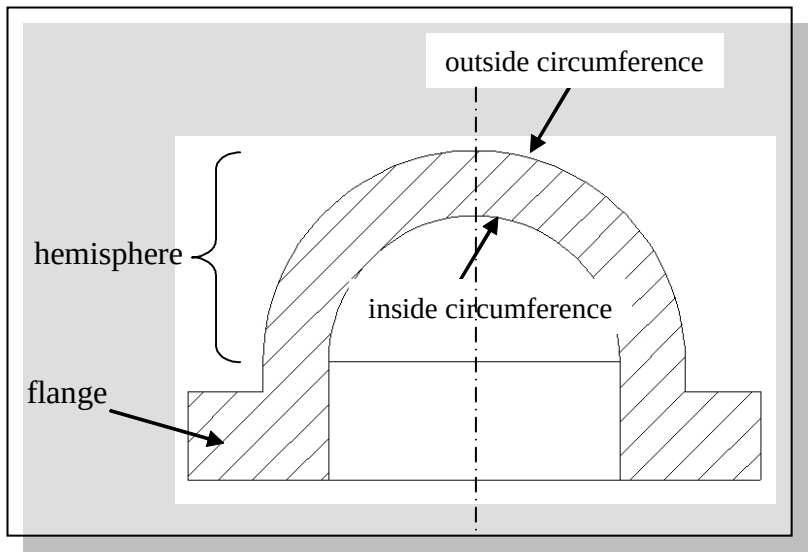
Objective

- **Develop methodology** to improve machine tool (MT) performance
  - cut circular arc (hemishell)
  - on 2-axis lathe
  - **Straightforward** to implement
    - G-code
  - Utilizes commercially available hardware
    - Ball bar, on-machine probe (OMP), tool set station

Cut Circular Trajectory

- Workpiece with circular trajectory
- **“Hemishell”**
  - “Easy to machine”
  - Incorporates movement of both axes
  - No backlash





2-Axis Vertical Turning Lathe

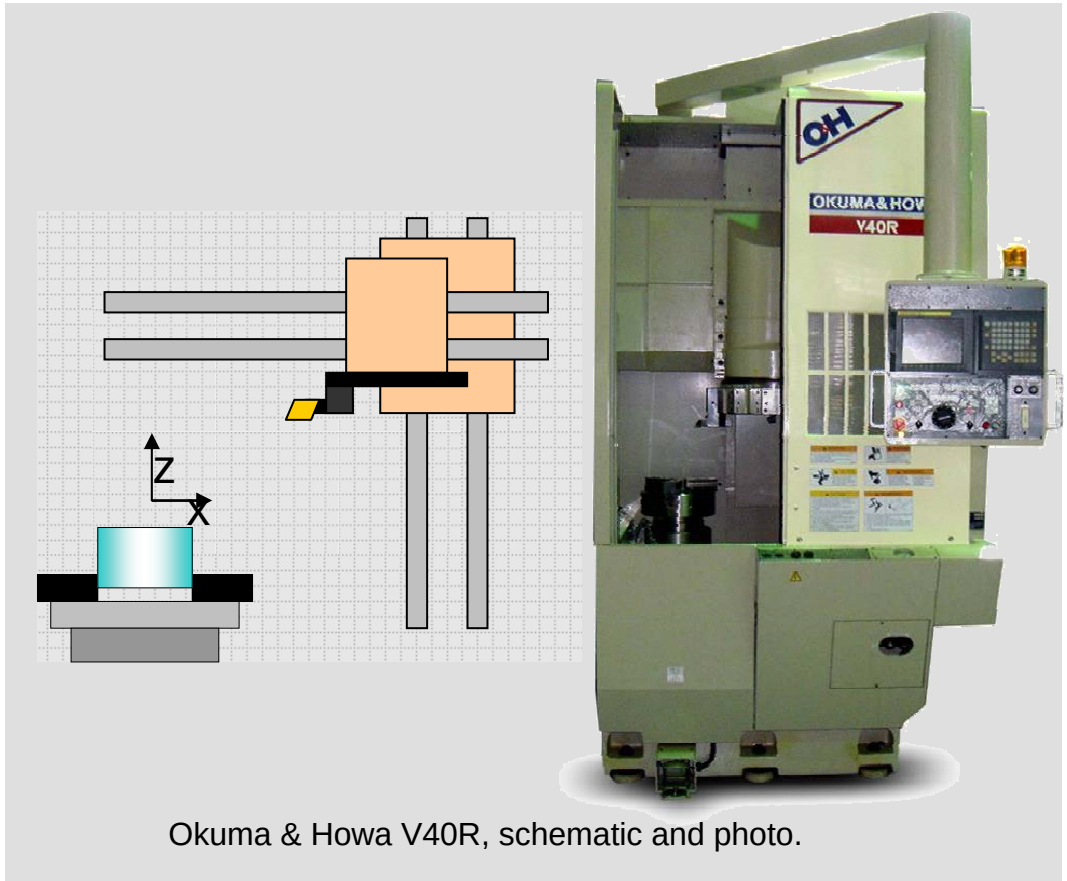
Repeatability:

X	**2.5 µm** (0.0001 in)
Z	**5.1 µm** (0.0002 in)

Resolution:

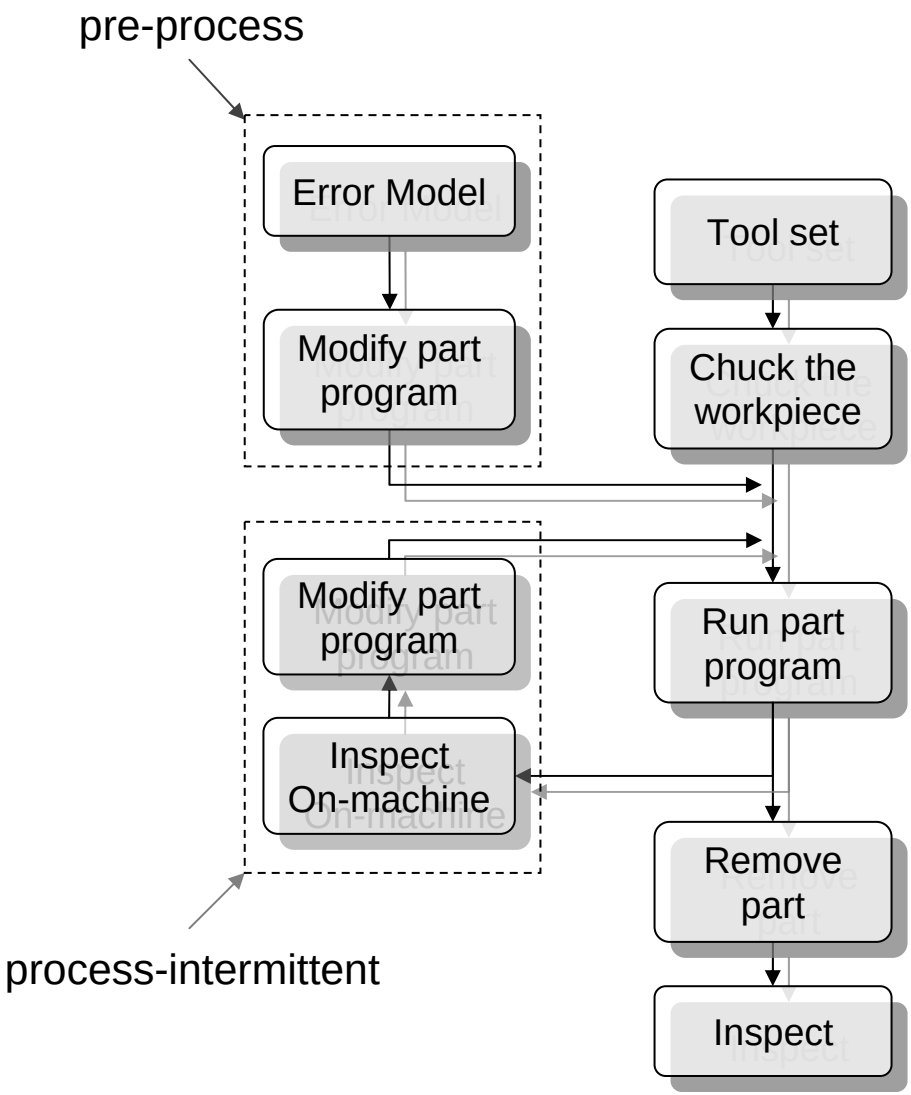
0.0001 in

(0.00254 mm)



Okuma & Howa V40R, schematic and photo.

Machining Procedure

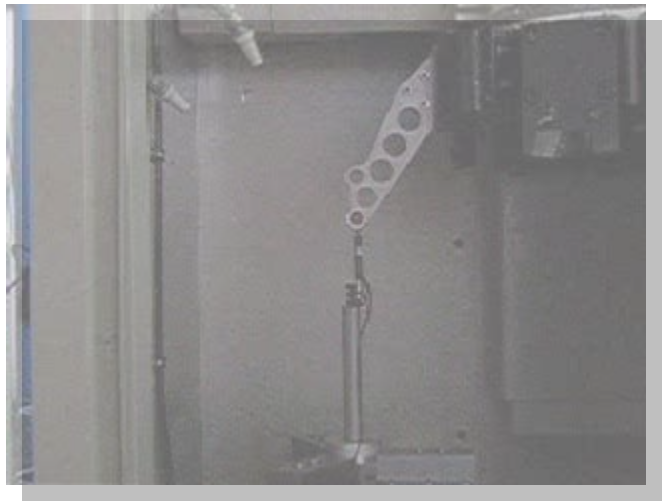


Equipment

- Ball bar (Pre-process)
  - Measures motion only
- OMP (Process-intermittent)
  - Includes motion and cutting effects
- CMM (Post-process)
  - Final inspection

Ball Bar

- Renishaw QC10
- Characterizes circular trajectory
- Particularly relevant



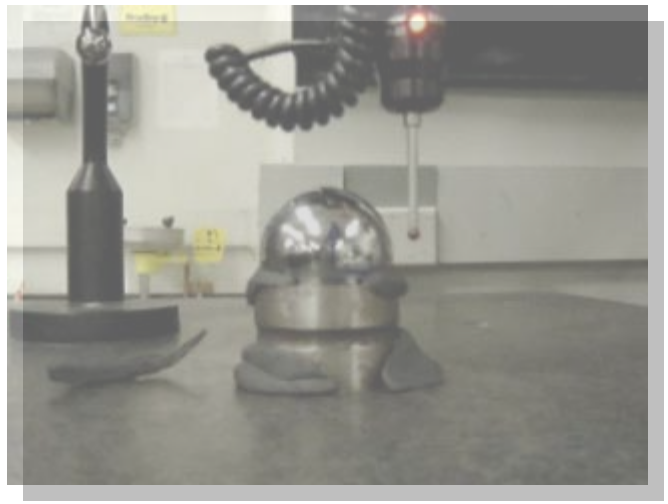
Ball bar on calibrator.

Touch Probe Inspection

- OMP
  - Process intermittent inspection

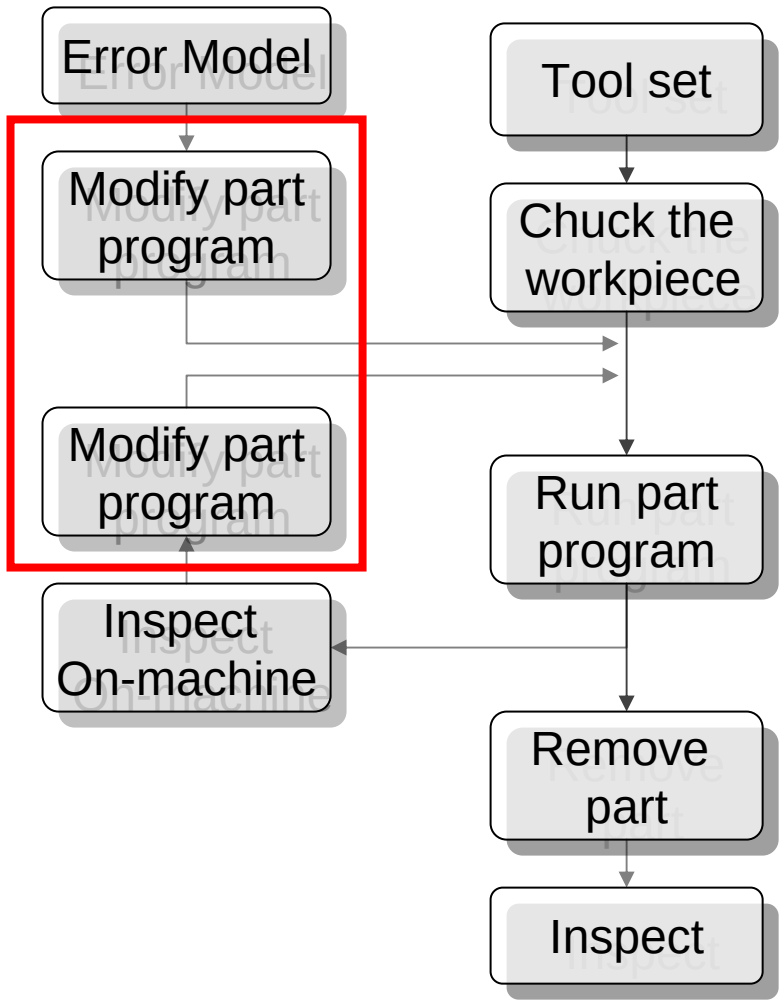
  - Traditionally used for datum location

- CMM
  - Post-process inspection



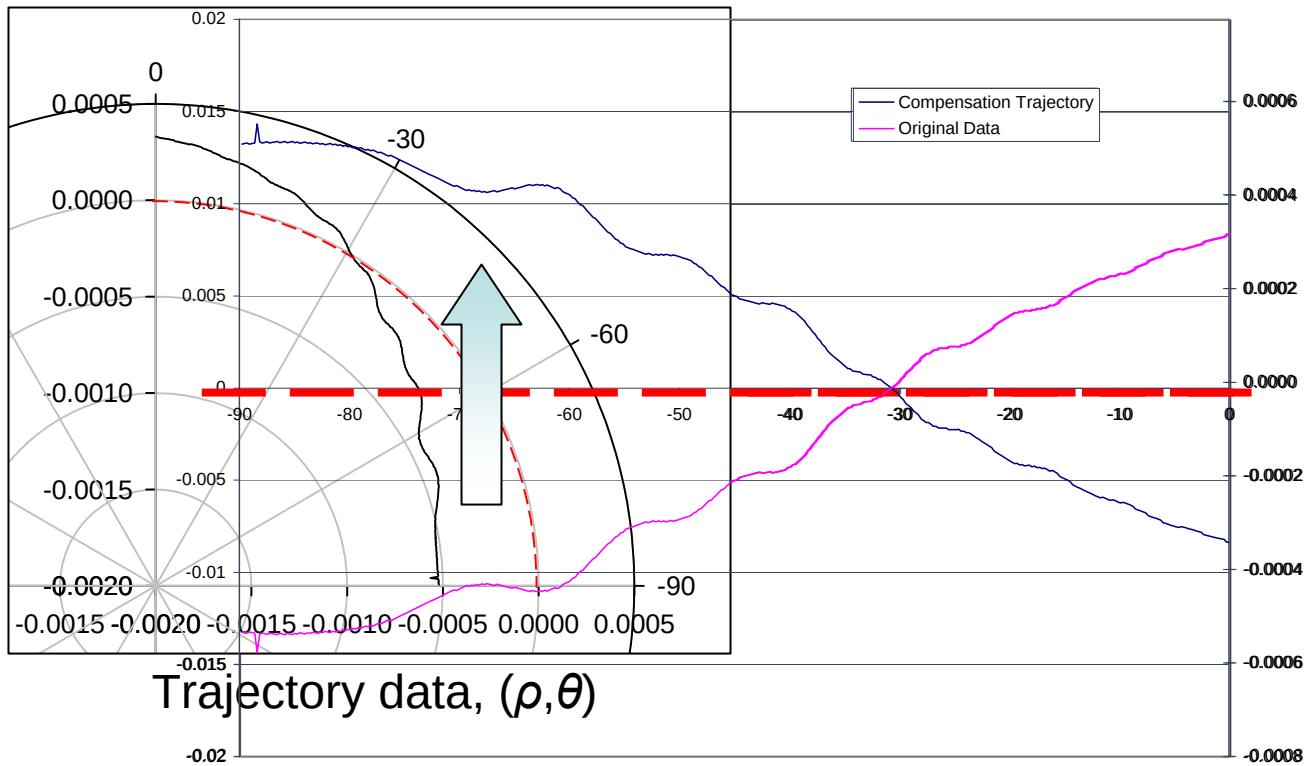
Compensation Strategy

- Based on
  - Ball bar
  - OMP
- Modify part program (G-code)

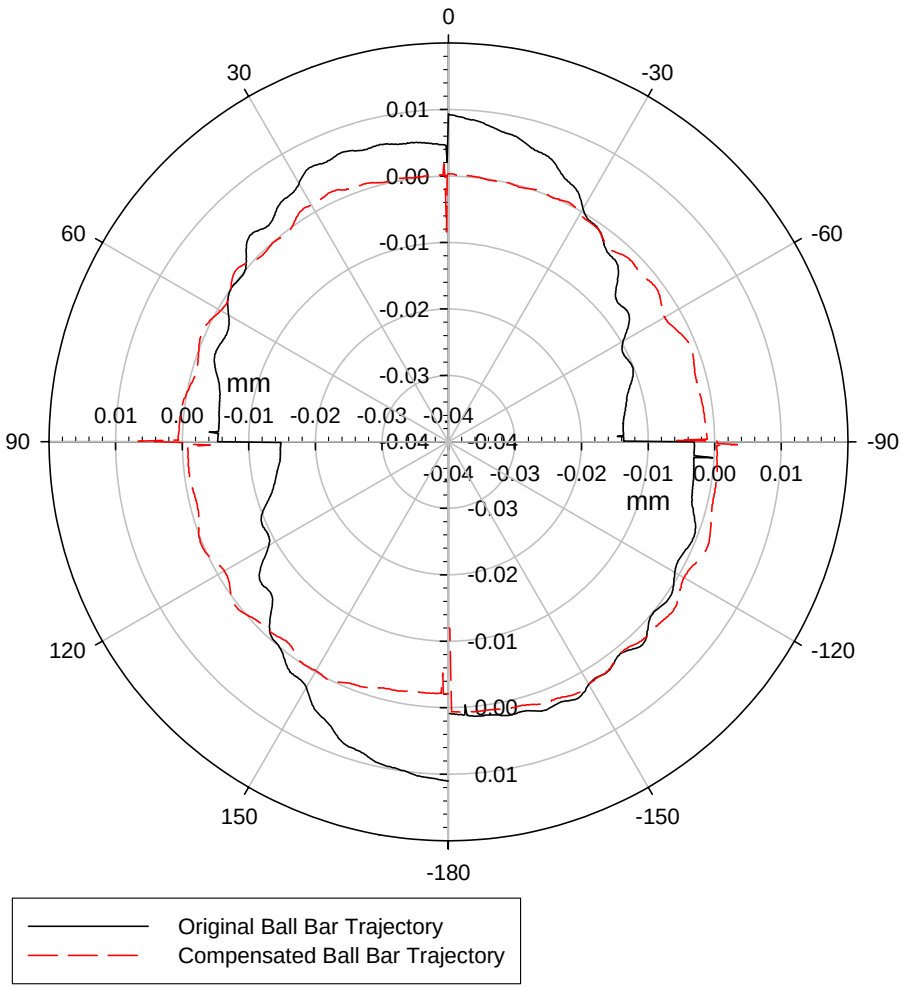


Generate New Trajectory

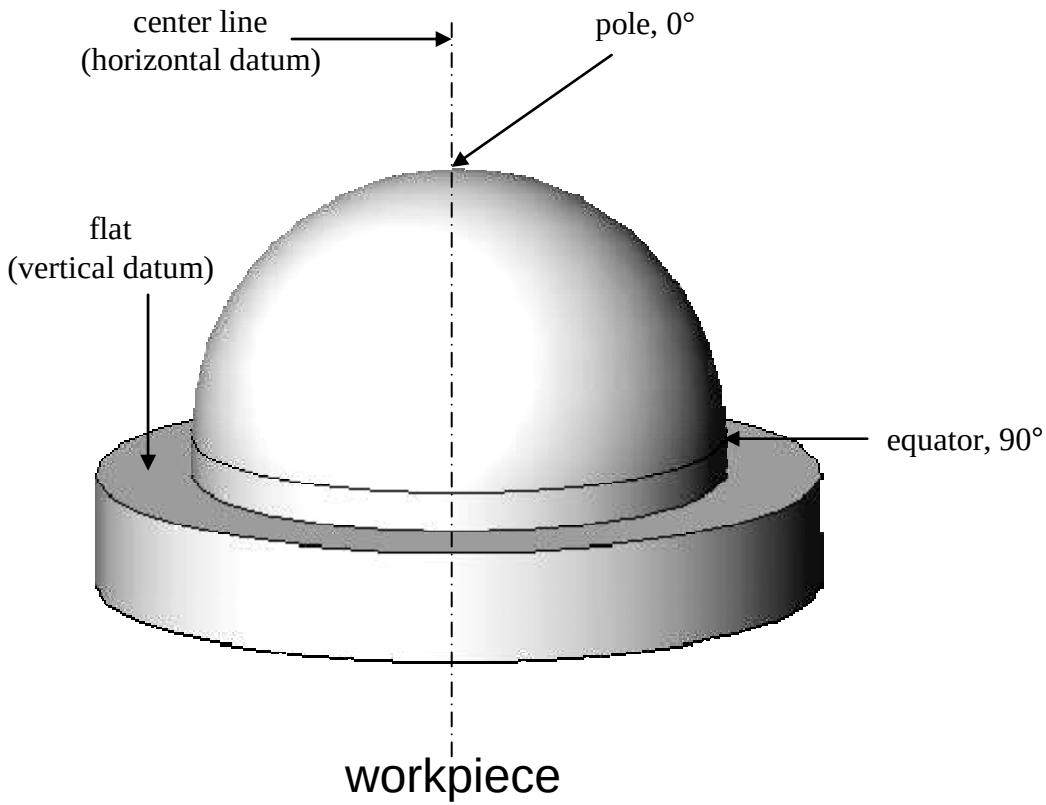
- “Invert about a line” measured



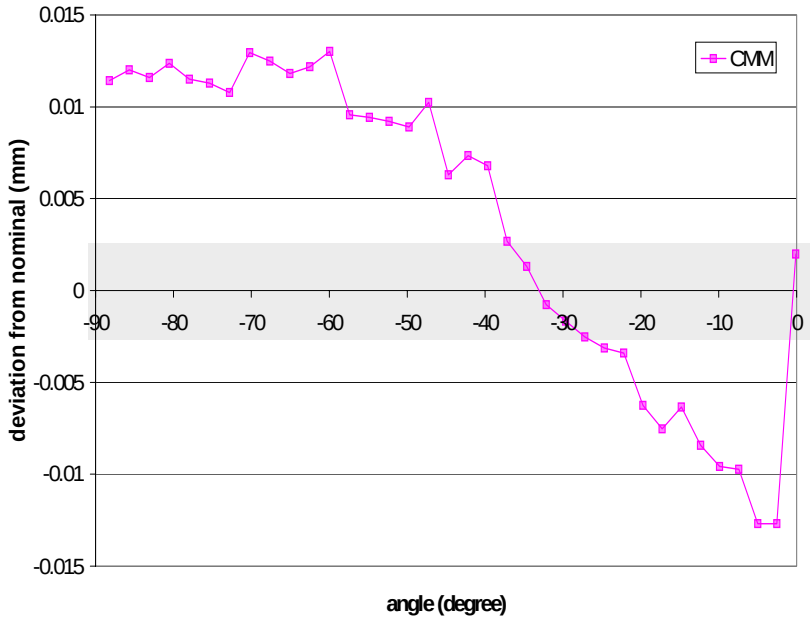
Ball Bar Compensation



	mm	
	original	comp.
average error	-0.001	0.000
standard deviation of error	0.007	0.001

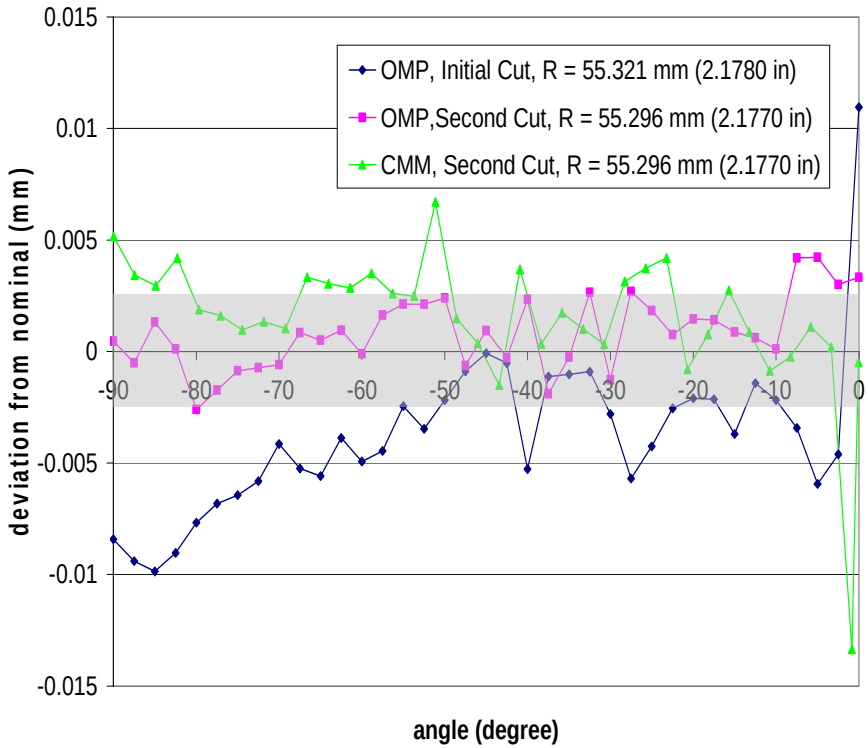

center line
(horizontal datum)
pole, 0°
flat
(vertical datum)
equator, 90°
workpiece

Ball Bar-Based Compensation



	mm	
	OMP	CMM
average error	-0.002	-0.004
standard deviation of error	0.006	0.005

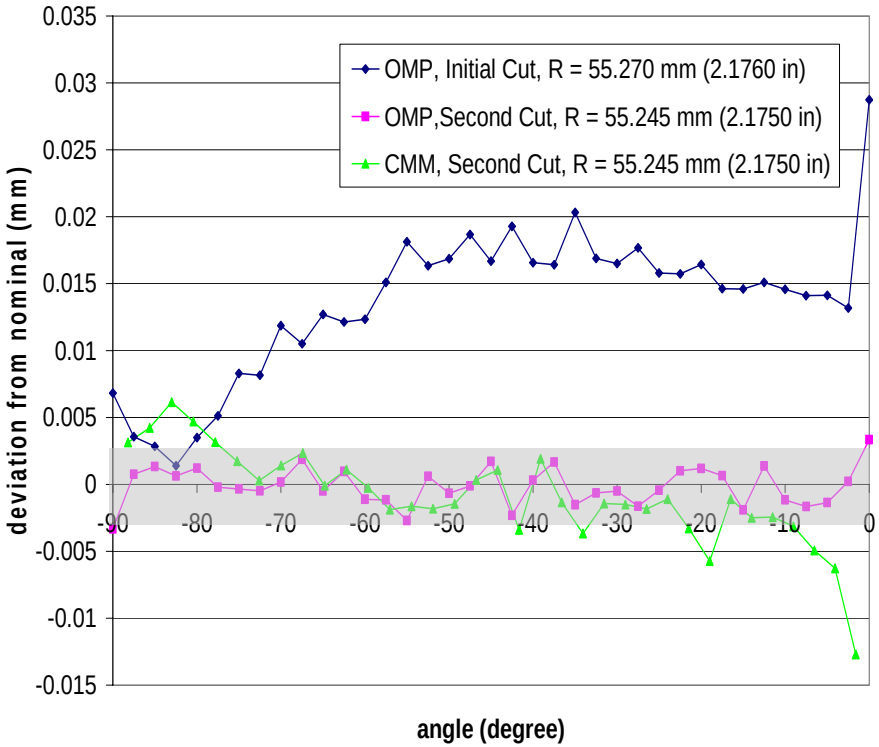
OMP Compensation



	mm		
	OMP of run 1(uncomp.)	OMP of run 2 (comp.)	CMM of run 2
average error	-0.004	0.001	0.002
standard deviation of error	0.004	0.002	0.003

OMP Compensation

- Large tool set error



	mm		
	OMP of run 1 (uncomp.)	OMP of run 2 (comp.)	CMM of run 2
average error	0.014	0.000	-0.001
standard deviation of error	0.006	0.001	0.004

Conclusions

- Ball Bar-based cutting compensation
  - Current method unsuccessful
  - Different method? Other factors?

- OMP-based cutting compensation
  - Limited by inspection accuracy (machine repeatability)
  - Accounts for errors

Contributions

- Developed a methodology for **integrating inspection** and machining on a vertical turning lathe
- Developed a strategy for **predicting** and **compensating trajectory errors**
- Characterized utility of **on-machine probe**, **ball bar**, **tool set station**, and tool set station for precision machining
- **Improved the accuracy** of circular tool paths for the Okuma & Howa V40R

Questions